POWER OUTPUT APPARATUS FOR HYBRID **IAP20 Rec'd PCT/PTO** 0 3 JAN 2006

FIELD OF THE INVENTION

    The present invention relates to a power output

5 apparatus, an automobile, and methods of controlling the same.

BACKGROUND OF THE INVENTION

    A proposed power output apparatus has an internal

combustion engine, a planetary gear unit that includes a

10 carrier linked with an output shaft of the internal combustion

engine and a ring gear linked with a drive shaft, a generator

that inputs and outputs power to and from a sun gear of the

planetary gear unit, and a motor that inputs and outputs power

to and from the drive shaft (see, for example, Japanese Patent

15 Laid-Open Gazette No. H11-55810). In the case of heat

generation in the generator or its driving circuit, this prior

art apparatus decreases the output torque of the internal

combustion engine and raises the revolution speed of the

internal combustion engine, so as to reduce the load of the

20 generator and prevent the heat generation in the generator

while maintaining a power demand to be output from the internal

combustion engine.

    In the power output apparatus that independently drives

the internal combustion engine and the drive shaft, in the

25 case of the occurrence of some disturbance like overheat of

the generator, the drive point of the internal combustion

engine is changed to respond to the disturbance while keeping the power demand to be output from the internal combustion engine unchanged. Keeping the power demand to be output from the internal combustion engine unchanged maintains the

5   driving force to be output to the drive shaft. When the motor that outputs power to the drive shaft is under a drive restriction due to heat generation in the motor or its driving circuit, however, the technique of keeping the power demand to be output from the internal combustion engine unchanged

10   may make the output from the internal combustion engine significantly greater than the output to the drive shaft and may cause an accumulator like a secondary battery to be excessively charged.

15   SUMMARY OF THE INVENTION

        The power output apparatus, the automobile, and their control methods of the invention aim to prevent an accumulator like a secondary battery from being excessively charged under a drive restriction of a motor that is capable of outputting

20   power to a drive shaft. The power output apparatus, the automobile, and their control methods of the invention also aim to ensure output of a power in the range of the drive restriction to the drive shaft under the drive restriction of the motor. The power output apparatus, the automobile, and

25   their control methods of the invention further aim to improve the emission under the drive restriction of the motor.

In order to attain at least part of the above aims, the power output apparatus, the automobile, and their control methods are constructed as follows.

A first power output apparatus of the present invention is
5   an apparatus that outputs power to a drive shaft, the power output apparatus including: an internal combustion engine; an electric power-mechanical power input-output module that is linked with an output shaft of the internal combustion engine and with the drive shaft and outputs at least part of
10   power from the internal combustion engine to the drive shaft through inputs and outputs of electric power and mechanical power; a motor that is capable of inputting and outputting power from and to the drive shaft; an accumulator that is capable of supplying and receiving electric power to and from
15   the electric power-mechanical power input-output module and the motor; a power demand setting module that sets a power demand required to the drive shaft, in response to an operator's manipulation; a target power setting module that sets a target power to be output from the internal combustion
20   engine, based on the setting of the power demand; a drive restriction effectuation module that, when a predetermined restricting condition is fulfilled, effects a drive restriction of the motor based on the predetermined restricting condition; a correction module that corrects the
25   setting of the target power based on the effected drive restriction, when the drive restriction of the motor is

4

effected by the drive restriction effectuation module; and a control module that executes normal control of controlling the internal combustion engine, the electric power-mechanical power input-output module, and the motor in the case of no

5 effectuation of the drive restriction of the motor by the drive restriction effectuation module to ensure output of the target power from the internal combustion engine and output of a power corresponding to the setting of the power demand to the drive shaft, the control module executing restriction control of

10 controlling the internal combustion engine, the electric power-mechanical power input-output module, and the motor in the case of effectuation of the drive restriction of the motor by the drive restriction effectuation module to ensure output of the corrected target power from the internal combustion

15 engine and output of a power in a range of the effected drive restriction from the motor.

Under no drive restriction of the motor, the first power output apparatus of the invention controls the internal combustion engine, the electric power-mechanical power

20 input-output module, and the motor to ensure output of the target power from the internal combustion engine and output of a power corresponding to the power demand to the drive shaft. Under the drive restriction of the motor, on the other hand, the first power output apparatus corrects the target

25 power based on the drive restriction and controls the internal combustion engine, the electric power-mechanical power

input-output module, and the motor to ensure output of the corrected target power from the internal combustion engine and output of a power in the drive restriction from the motor. Namely, the target power is corrected to change the drive point

5   of the internal combustion engine under the drive restriction of the motor. The arrangement of the invention effectively prevents the accumulator from being excessively charged and ensures output of the power in the range of the drive restriction to the drive shaft. This desirably prevents

10   deterioration of the emission by output of a power corresponding to the power demand from the internal combustion engine under the drive restriction of the motor.

In one preferable embodiment of the invention, the first power output apparatus further includes a charge-discharge

15   electric power measurement module that measures a charge-discharge electric power used to charge the accumulator or obtained by discharging the accumulator; and an electric power demand setting module that sets an electric power demand for charging or discharging the accumulator,

20   based on a predetermined charge-discharge condition. The correction module corrects the target power to cancel a difference between the charge-discharge electric power measured by the charge-discharge electric power measurement module and the electric power demand set by the electric power

25   demand setting module. The electric power used to charge the accumulator or obtained by discharging the accumulator thus

6

significantly approaches to the electric power demand. This arrangement effectively prevents the accumulator from being excessively charged.

In one preferable application of the first power output apparatus of the invention, the target power setting module specifies a target torque and a target revolution speed to set the target power, and the correction module varies the specified target revolution speed to correct the target power. The drive point of the internal combustion engine is thus changed, while the torque output from the internal combustion engine is kept unchanged. This arrangement desirably reduces the effects of a varying output of the power to the drive shaft by the electric power-mechanical power input-output module with a variation in target power.

In another preferable application of the first power output apparatus of the invention, the control module executes the restriction control on a condition that the power demand is in a predetermined light load power range, when the drive restriction of the motor is effected by the drive restriction effectuation module. Such control is restrictively executed in a light load state, while different control is adopted in a heavy load state. This arrangement ensures adequate control in response to the operator's requirement.

A second power output apparatus of the present invention is an apparatus that outputs power to a drive shaft, the power output apparatus including: an internal combustion engine;

an electric power-mechanical power input-output module that
is linked with an output shaft of the internal combustion
engine and with the drive shaft and outputs at least part of
power from the internal combustion engine to the drive shaft

5   through inputs and outputs of electric power and mechanical
power; a motor that is capable of inputting and outputting
power from and to the drive shaft; an accumulator that is
capable of supplying and receiving electric power to and from
the electric power-mechanical power input-output module and

10   the motor; and a control module that sets a power demand
required to the drive shaft in response to an operator's
manipulation and sets a target power to be output from the
internal combustion engine based on the setting of the power
demand,   the   control   module   controlling   the   internal

15   combustion   engine,   the   electric   power-mechanical   power
input-output module,   and the motor   in   the   case   of   no
fulfillment   of   a   predetermined   restricting   condition   to
ensure output of the target power from the internal combustion
engine and output of a power corresponding to the power demand

20   to   the   drive   shaft,   in   the   case   of   fulfillment   of   the
predetermined   restricting   condition,   the   control   module
effecting   a   drive   restriction   of   the   motor   based   on   the
predetermined restricting condition, correcting the setting
of the target power based on the effected drive restriction,

25   and controlling the internal combustion engine, the electric
power-mechanical power input-output module, and the motor to

8

ensure output of the corrected target power from the internal combustion engine and output of a power in a range of the effected drive restriction from the motor.

Under no drive restriction of the motor, the second power
5 output apparatus of the invention controls the internal combustion engine, the electric power-mechanical power input-output module, and the motor to ensure output of the target power from the internal combustion engine and output of a power corresponding to the power demand to the drive
10 shaft. Under the drive restriction of the motor, on the other hand, the second power output apparatus corrects the target power based on the drive restriction and controls the internal combustion engine, the electric power-mechanical power input-output module, and the motor to ensure output of the
15 corrected target power from the internal combustion engine and output of a power in the drive restriction from the motor. Namely, the target power is corrected to change the drive point of the internal combustion engine under the drive restriction of the motor. The arrangement of the invention effectively
20 prevents the accumulator from being excessively charged and ensures output of the power in the range of the drive restriction to the drive shaft. This desirably prevents deterioration of the emission by output of a power corresponding to the power demand from the internal combustion
25 engine under the drive restriction of the motor.

In the first or the second power output apparatus discussed above, the electric power-mechanical power input-output module may include: a three-shaft power input-output assembly that is connected with three shafts, that is, the output shaft

5   of the internal combustion engine, the drive shaft, and a third shaft, and specifies input and output of power from and to one residual shaft among the three shafts, based on powers input and output from and to two shafts among the three shafts; and a generator that inputs and outputs power from and to the

10 third shaft.   In the first or the second power output apparatus discussed above, the electric power-mechanical power input-output module may include a pair-rotor generator having a first rotor, which is linked with the output shaft of the internal combustion engine, and a second rotor, which

15 is linked with the drive shaft and rotates relative to the first rotor, the pair-rotor generator outputting at least part of the power from the internal combustion engine to the drive shaft through input and output of electric power by electromagnetic interaction between the first rotor and the

20 second rotor.

The power output apparatus of any application mentioned above may be mounted on an automobile.   Specifically, an automobile of the present invention includes: an internal combustion engine; an electric power-mechanical power input-output

25 module that is linked with an output shaft of the internal combustion engine and with a drive shaft coupled with an axle

and outputs at least part of power from the internal combustion engine to the drive shaft through inputs and outputs of electric power and mechanical power; a motor that is capable of inputting and outputting power from and to the drive shaft;

5 an accumulator that is capable of supplying and receiving electric power to and from the electric power-mechanical power input-output module and the motor; a power demand setting module that sets a power demand required to the drive shaft, in response to an operator's manipulation; a target power

10 setting module that sets a target power to be output from the internal combustion engine, based on the setting of the power demand; a drive restriction effectuation module that, when a predetermined restricting condition is fulfilled, effects a drive restriction of the motor based on the predetermined

15 restricting condition; a correction module that corrects the setting of the target power based on the effected drive restriction, when the drive restriction of the motor is effected by the drive restriction effectuation module; and a control module that executes normal control of controlling

20 the internal combustion engine, the electric power-mechanical power input-output module, and the motor in the case of no effectuation of the drive restriction of the motor by the drive restriction effectuation module to ensure output of the target power from the internal combustion engine and output of a power

25 corresponding to the setting of the power demand to the drive shaft, the control module executing restriction control of

controlling the internal combustion engine, the electric power-mechanical power input-output module, and the motor in the case of effectuation of the drive restriction of the motor by the drive restriction effectuation module to ensure output

5   of the corrected target power from the internal combustion engine and output of a power in a range of the effected drive restriction from the motor.   Another automobile of the present invention includes: an internal combustion engine; an electric power-mechanical power input-output module that

10   is linked with an output shaft of the internal combustion engine and with the drive shaft coupled with an axle and outputs at least part of power from the internal combustion engine to the drive shaft through inputs and outputs of electric power and mechanical power; a motor that is capable

15   of inputting and outputting power from and to the drive shaft; an accumulator that is capable of supplying and receiving electric power to and from the electric power-mechanical power input-output module and the motor; and a control module that sets a power demand required to the drive shaft in response

20   to an operator's manipulation and sets a target power to be output from the internal combustion engine based on the setting of the power demand, the control module controlling the internal combustion engine, the electric power-mechanical power input-output module, and the motor in the case of no

25   fulfillment of a predetermined restricting condition to ensure output of the target power from the internal combustion

engine and output of a power corresponding to the power demand
to the drive shaft, in the case of fulfillment of the
predetermined restricting condition, the control module
effecting a drive restriction of the motor based on the

5   predetermined restricting condition, correcting the setting
of the target power based on the effected drive restriction,
and controlling the internal combustion engine, the electric
power-mechanical power input-output module, and the motor to
ensure output of the corrected target power from the internal

10   combustion engine and output of a power in a range of the
effected drive restriction from the motor.

In one preferable embodiment of the invention, one of the
automobiles discussed above further includes: a
charge-discharge electric power measurement module that

15   measures a charge-discharge electric power used to charge the
accumulator or obtained by discharging the accumulator; and
an electric power demand setting module that sets an electric
power demand for charging or discharging the accumulator,
based on a predetermined charge-discharge condition. The

20   correction module corrects the setting of the target power
to cancel a difference between the charge-discharge electric
power measured by the charge-discharge electric power
measurement module and the electric power demand set by the
electric power demand setting module. In one preferable

25   application of the automobiles discussed above, the target
power setting module specifies a target torque and a target

revolution speed to set the target power, and the correction module may vary the specified target revolution speed to correct the target power. In another preferable application of the automobile discussed above, the control module executes

5   the restriction control on a condition that the power demand is in a predetermined light load power range, when the drive restriction of the motor is effected by the drive restriction effectuation module.

The technique of the power output apparatus and the

10   automobile with the power output apparatus mounted thereon of the present invention is also applicable to a control method for a power output apparatus or for an automobile. A control method of the present invention is a method for a power output apparatus or an automobile, that includes: an internal

15   combustion engine; an electric power-mechanical power input-output module that is linked with an output shaft of the internal combustion engine and with a drive shaft and outputs at least part of power from the internal combustion engine to the drive shaft through inputs and outputs of

20   electric power and mechanical power; a motor that is capable of inputting and outputting power to and from the drive shaft; and an accumulator that is capable of supplying and receiving electric power to and from the electric power-mechanical power input-output module and the motor, the control method

25   including the steps of: (a) setting a power demand required to the drive shaft, in response to an operator's manipulation;

(b) setting a target power to be output from the internal combustion engine, based on the setting of the power demand; (c) when a predetermined restricting condition is fulfilled, effecting a drive restriction of the motor based on the

5 predetermined restricting condition; (d) correcting the setting of the target power based on the effected drive restriction, in the case of effectuation of the drive restriction of the motor; and (e) controlling the internal combustion engine, the electric power-mechanical power

10 input-output module, and the motor in the case of no effectuation of the drive restriction of the motor to ensure output of the target power from the internal combustion engine and output of a power corresponding to the setting of the power demand to the drive shaft, while controlling the internal

15 combustion engine, the electric power-mechanical power input-output module, and the motor in the case of effectuation of the drive restriction of the motor to ensure output of the corrected target power from the internal combustion engine and output of a power in a range of the effected drive

20 restriction from the motor.

In one preferable embodiment of the invention, the control method further includes, prior to the step (d), the steps of: (f) measuring a charge-discharge electric power used to charge the accumulator or obtained by discharging the

25 accumulator; and (g) setting an electric power demand for charging or discharging the accumulator, based on a

predetermined charge-discharge condition. The step (d) corrects the target power to cancel a difference between the observed charge-discharge electric power and the setting of the electric power demand.

5 Brief Description of the Drawings

Fig. 1 schematically illustrates the construction of a hybrid vehicle 20 in one embodiment of the invention; Fig. 2 is a flowchart showing a drive control routine executed by a hybrid electronic control unit 70; Fig. 3 shows an example of a torque

10 demand setting map; Fig. 4 shows an example of a driving line of an engine 22 and a process of setting a target revolution speed Ne* and a target torque Te*; Fig. 5 is an alignment chart showing a dynamic relation with respect to a rotational elements in a power distribution integration mechanism 30;

15 Fig. 6 is a flowchart showing a light load correction routine; Fig. 7 is a flowchart showing a heavy load correction routine; Fig. 8 shows a driving line of the engine 22 and a process of correcting a target drive point; Fig. 9 shows the relation between power of the engine 22 and power of a motor MG2 in

20 an ordinary state and under drive restriction of the motor MG2; Fig. 10 shows a process of correcting the target drive point according to a heavy load driving line; Fig. 11 schematically illustrates the construction of a hybrid vehicle 120 in one modified embodiment; and Fig. 12

25 schematically illustrates the construction of a hybrid vehicle 220 in another modified embodiment.

DETAILED DESCRIPTION

One mode of carrying out the invention is discussed below as a preferred embodiment. Fig. 1 schematically illustrates the

5   construction of a hybrid vehicle 20 with a power output apparatus mounted thereon in one embodiment of the invention. As illustrated, the hybrid vehicle 20 of the embodiment includes an engine 22, a three shaft-type power distribution integration mechanism 30 that is linked with a crankshaft 26

10   functioning as an output shaft of the engine 22 via a damper 28, a motor MG1 that is linked with the power distribution integration mechanism 30 and is capable of generating electric power; a reduction gear 35 that is attached to a ring gear shaft 32a functioning as a drive shaft connected with the power

15   distribution integration mechanism 30, another motor MG2 that is linked with the reduction gear 35, and a hybrid electronic control unit 70 that controls the whole power output apparatus.

      The engine 22 is an internal combustion engine that

20   consumes a hydrocarbon fuel, such as gasoline or light oil, to output power and is under control of an engine electronic control unit (hereafter referred to as engine ECU) 24. The engine ECU 24 receives input signals from various sensors detecting the driving conditions of the engine 22 and carries

25   out operation control including fuel injection control, ignition control, and intake air flow regulation. The engine

ECU 24 communicates with the hybrid electronic control unit 70 and receives control signals from the hybrid electronic control unit 70 to control the operations of the engine 22, while outputting data regarding the driving conditions of the

5   engine 22 to the hybrid electronic control unit 70 according to the requirements.

The power distribution and integration mechanism 30 has a sun gear 31 that is an external gear, a ring gear 32 that is an internal gear and is arranged concentrically with the sun gear

10   31, multiple pinion gears 33 that engage with the sun gear 31 and with the ring gear 32, and a carrier 34 that holds the multiple pinion gears 33 in such a manner as to allow free revolution thereof and free rotation thereof on the respective axes. Namely the power distribution and integration

15   mechanism 30 is constructed as a planetary gear mechanism that allows for differential motions of the sun gear 31, the ring gear 32, and the carrier 34 as rotational elements. The carrier 34, the sun gear 31, and the ring gear 32 in the power distribution and integration mechanism 30 are respectively

20   coupled with the crankshaft 26 of the engine 22, the motor MG1, and the reduction gear 35 via the ring gear shaft 32a. While the motor MG1 functions as a generator, the power output from the engine 22 and input through the carrier 34 is distributed into the sun gear 31 and the ring gear 32 according

25   to the gear ratio. While the motor MG1 functions as a motor, on the other hand, the power output from the engine 22 and

18

input through the carrier 34 is combined with the power output from the motor MG1 and input through the sun gear 31 and the composite power is output to the ring gear 32. The power output to the ring gear 32 is finally transmitted to the driving

5   wheels 63a, 63b via the gear mechanism 60 and differential gear 62 from ring gear shaft 32a.

Both of the motors MG1 and MG2 are constructed as known synchronous generator motors, which are driven as an electric generator as well as an electric motor. The motors MG1 and

10   MG2 transmit electric power from and to a battery 50 via inverters 41 and 42. A power line 54 connecting the inverters 41 and 42 with the battery 50 includes a positive terminal bus line and a negative terminal bus line shared by the two inverters 41 and 42. This arrangement enables the electric

15   power generated by one of the motors MG1 and MG2 to be consumed by the other motor. The battery 50 is charged with the excess electric power of the motor MG1 or the motor MG2 and is discharged to supplement the insufficient electric power of the motor MG1 or the motor MG2. The battery 50 is neither

20   charged not discharged when there is an electric power balance by the motors MG1 and MG2. The motors MG1 and MG2 are both driven and controlled by a motor electronic control unit (hereinafter referred to as motor ECU) 40. The motor ECU 40 receives signals required for driving and controlling the

25   motors MG1 and MG2, for example, signals from rotational position detection sensors 43 and 44 that detect the

rotational positions of rotors in the motors MG1 and MG2 and values of phase electric currents supplied to the motors MG1 and MG2 and detected by non-illustrated electric current sensors. The motor ECU 40 outputs switching control signals

5   to the inverters 41 and 42. The motor ECU 40 communicates with the hybrid electronic control unit 70 and drives and controls the motors MG1 and MG2 in response to control signals from the hybrid electronic control unit 70 while outputting data regarding the driving conditions of the motors MG1 and MG2

10   to the hybrid electronic control unit 70 according to the requirements.

The battery 50 is controlled by a battery electronic control unit (hereinafter referred to as battery ECU) 52. The battery ECU 52 receives signals required for controlling the

15   battery 50, for example, a value of inter-terminal voltage Vb measured by a voltage sensor 51a disposed between terminals of the battery 50, a value of charge discharge electric current Ib measured by an electric current sensor 51b attached to the power line 54 connecting with an output terminal of the battery

20   50, and a battery temperature Tb measured by a temperature sensor 51c attached to the battery 50. The battery ECU 52 outputs data regarding the conditions of the battery 50 to the hybrid electronic control unit 70 via communication according to the requirements. The battery ECU 52 computes

25   a state of charge (SOC) from an accumulated value of the charge

discharge electric current Ib measured by the electric current sensor 51b for controlling the battery 50.

The hybrid electronic control unit 70 is constructed as a microprocessor including a CPU 72, a ROM 74 that stores

5   processing programs, a RAM 76 that temporarily stores data, and a non-illustrated input-output port, and a non-illustrated communication port. The hybrid electronic control unit 70 receives various inputs via the input port: a motor temperature Tm from a temperature sensor 46 attached

10   to the motor MG2, an inverter temperature Tinv from a temperature sensor 47 attached to the inverter 42, an ignition signal from an ignition switch 80, a gearshift position SP from a gearshift position sensor 82 that detects the current position of a gearshift lever 81, an accelerator opening Acc

15   from an accelerator pedal position sensor 84 that measures a step-on amount of an accelerator pedal 83, a brake pedal position BP from a brake pedal position sensor 86 that measures a step-on amount of a brake pedal 85, and a vehicle speed V from a vehicle speed sensor 88. The hybrid electronic control

20   unit 70 communicates with the engine ECU 24, the motor ECU 40, and the battery ECU 52 via the communication port to transmit diverse control signals and data to and from the engine ECU 24, the motor ECU 40, and the battery ECU 52, as mentioned previously.

25   The hybrid vehicle 20 of the embodiment thus constructed calculates a required torque, which is to be output to the

ring gear shaft 32a or the drive shaft, based on the accelerator opening Acc corresponding to the driver's step-on amount of the accelerator pedal 83 and the vehicle speed V. The engine 22 and the motors MG1 and MG2 are under operation

5 control to enable power corresponding to the calculated required torque to be actually output to the ring gear shaft 32a. The operation control of the engine 22 and the motors MG1 and MG2 has multiple modes, a torque conversion drive mode, a charge-discharge drive mode, and a motor drive mode. In the

10 torque conversion drive mode, the engine 22 is under operation control to output a power equivalent to the required power. The motors MG1 and MG2 are driven and controlled to cause the total power output from the engine 22 to be subjected to the torque conversion by means of the power distribution and

15 integration mechanism 30 and the motors MG1 and MG2 and to be output to the ring gear shaft 32a. In the charge-discharge drive mode, the engine 22 is under operation control to output a power equivalent to the sum of the required power and an electric power used for charging and discharging the battery

20 50. The motors MG1 and MG2 are driven and controlled to cause all or part of the power output from the engine 22 with a charge or a discharge of the battery 50 to be subjected to the torque conversion by means of the power distribution and integration mechanism 30 and the motors MG1 and MG2 and to be output as

25 the required power to the ring gear shaft 32a. In the motor drive mode, the operation of the engine 22 is at a stop, while

the motor MG2 is driven and controlled to output a power equivalent to the required power to the ring gear shaft 32a.

The following describes the operations of the hybrid vehicle 20 of the embodiment constructed as discussed above, especially the operation under a drive restriction of the motor MG2 due to a temperature rise of the motor MG2 or the inverter 42. Fig. 2 is a flowchart showing a drive control routine executed by the hybrid electronic control unit 70. This routine is carried out repeatedly at preset time intervals (for example, at every 8 msec).

When the drive control routine starts, the CPU 72 of the hybrid electronic control unit 70 first inputs various data required for control, that is, the accelerator opening Acc from the accelerator pedal position sensor 84, the vehicle speed V from the vehicle speed sensor 88, revolution speeds Nm1 and Nm2 of the motors MG1 and MG2, and a drive limit Tlim of the motor MG2 (step S100). The procedure of this embodiment receives the revolution speeds Nm1 and Nm2 of the motors MG1 and MG2, which have been calculated according to rotational positions of rotors in the motors MG1 and MG2 detected by rotational position detection sensors 43 and 44, from the motor ECU 40 via communication. The procedure of this embodiment reads out and inputs the drive limit Tlim of the motor MG2, which has been set according to a non-illustrated drive limit setting routine based on the motor temperature Tm from the temperature sensor 46 attached to the

motor MG2, the inverter temperature Tinv from the temperature sensor 47 attached to the inverter 42, and the revolution speed Nm2 of the motor MG2 and has been written at a specified address in the RAM 76. The drive limit Tlim is set, for example, as

5   a value of 60% or 50% of a rated maximum torque of the motor MG2 at the revolution speed Nm2, when the motor temperature Tm or the inverter temperature Tinv is not lower than an upper limit motor temperature or an upper limit inverter temperature set as the upper threshold to ensure continuous actuation of

10   the motor MG2. In this embodiment, when the motor temperature Tm or the inverter temperature Tinv is lower than the upper limit motor temperature or the upper limit inverter temperature, a rated maximum torque of the motor MG2 at a revolution speed Ne is set to the drive limit Tlim. For the

15   better understanding of explanation, the following description first regards the procedure without a drive restriction of the motor MG2 and the procedure under a drive restriction of the motor MG2.

       After the input of these data, the CPU 72 sets a torque

20   demand Tr* to be output to the ring gear shaft 32a or the drive shaft linked with the drive wheels 63a and 63b as the torque required for the vehicle and a power demand Pe* to be output from the engine 22, based on the inputs of the accelerator opening Acc and the vehicle speed V (step S110). In the

25   structure of this embodiment, variations in torque demand Tr* against the accelerator opening Acc and the vehicle speed V

are specified in advance and stored as a torque demand setting map in the ROM 74. The procedure of the embodiment reads and sets the torque demand Tr* corresponding to the given accelerator opening Acc and the given vehicle speed V from

5   the stored torque demand setting map. Fig. 3 shows an example of the torque demand setting map. The power demand Pe* is calculated as the sum of the product of the setting of the torque demand Tr* and a revolution speed Nr of the ring gear shaft 32a, a charge-discharge power demand Pb* of the battery

10   50, and a potential loss 'Loss'. The revolution speed Nr of the ring gear shaft 32a may be obtained by multiplying the vehicle speed V by a conversion coefficient k or by dividing the revolution speed Nm2 of the motor MG2 by a gear ratio Gr of the reduction gear 35.

15   After setting the torque demand Tr* and the power demand Pe*, a target revolution speed Ne* and a target torque Te* of the engine 22 are set according to the setting of the power demand Pe* (step S120). Here the target revolution speed Ne* and the target torque Te* are set according to a driving line

20   for efficiently driving the engine 22 and the setting of the power demand Pe*. An example of the driving line of the engine 22 and the process of setting the target revolution speed Ne* and the target torque Te* are shown in Fig. 4. As illustrated, the target revolution speed Ne* and the target torque Te* are

25   obtained as the intersection of the driving line and a curve of constant power demand Pe* (= Ne*Te*).

After setting the target revolution speed Ne* and the target torque Te*, it is determined whether the motor MG2 is under a drive restriction (step S130). The presence of the drive restriction of the motor MG2 may be specified according

5   to the value of the drive limit Tlim or according to the value of a flag, which may be set to effect the drive restriction of the motor MG2.

The description first regards the case without a drive restriction of the motor MG2. The routine thus gives a

10 negative answer in this cycle at step S130 and goes to the processing of and after step S170. The CPU 72 calculates a target revolution speed Nm1* of the motor MG1 from the setting of the target revolution speed Ne*, the revolution speed Nr (= Nm2/Gr) of the ring gear shaft 32a, and a gear ratio of

15 the power distribution integration mechanism 30 according to Equation (1) given below, while calculating a torque command Tm1* of the motor MG1 from the calculated target revolution speed Nm1* and the current revolution speed Nm1 according to Equation (2) given below (step S170). Equation (1) shows a

20 dynamic relation of the rotational elements in the power distribution integration mechanism 30. Fig. 5 is an alignment chart showing a dynamic relation between the revolution speed and the torque with respect to the rotational elements in the power distribution integration mechanism 30.

25 An axis S shows the revolution speed of the sun gear 31 that is equal to the revolution speed Nm1 of the motor MG1. An axis

C shows the revolution speed of the carrier 34 that is equal
to the revolution speed Ne of the engine 22. An axis R shows
the revolution speed Nr of the ring gear 32 that is obtained
by multiplying the revolution speed Nm2 of the motor MG2 by
5   the gear ratio Gr of the reduction gear 35. Equation (1) is
easily derived from this alignment chart. Two thick arrows
on the axis R respectively represent a torque acting on the
ring gear shaft 32a as a torque Te* output from the engine
22 is transmitted via the power distribution integration
10   mechanism 30 while the engine 22 is steadily driven at a
specific drive point defined by the target torque Te* and the
target revolution speed Ne*, and a torque acting on the ring
gear shaft 32a as a torque Tm2* output from the motor MG2 is
transmitted via the reduction gear 35. Equation (2) shows a
15   relation in feedback control to rotate the motor MG1 at the
target revolution speed Nm1*. In Equation (2), 'k1' in the
second term on the right side represents a gain of a
proportional term and 'k2' in the third term on the right side
represents a gain of an integral term.

20

$$Nm1^* = Ne^* \ddot{y}(1+\ddot{y})/\ddot{y} - Nm2/(Gr\ddot{y}\ddot{y}) \; \ddot{y}\ddot{y}\ddot{y}\ddot{y}\ddot{y}\ddot{y}\ddot{y}\ddot{y}\ddot{y} \qquad (1)$$

$$Tm1^* = \text{Previous } Tm1^* + k1(Nm1^* - Nm1) + k2(Nm1^* - Nm1)dt \qquad (2)$$

After calculation of the target revolution speed Nm1*
25   and the torque command Tm1* of the motor MG1, the CPU 72 divides
a difference between an output limit Wout of the battery 50

and a power consumption (generated power) of the motor MG1, which is the product of the calculated torque command Tm1* of the motor MG1 and the current revolution speed Nm1 of the motor MG1, by the current revolution speed Nm2 of the motor

5   MG2 according to Equation (3) given below to calculate a torque limit Tmax as an upper limit torque output from the motor MG2 (step S180). The CPU 72 also calculates a tentative motor torque Tm2tmp as a torque to be output from the motor MG2 from the torque demand Tr*, the torque command Tm1*, and the gear

10   ratio of the power distribution integration mechanism 30 according to Equation (4) given below (step S190), and sets the smallest among the calculated torque limit Tmax, the calculated tentative motor torque Tm2tmp, and the drive limit Tlim to a torque command Tm2* of the motor MG2 (step S200).

15   In this cycle of the routine, there is no drive restriction of the motor MG2. The rated maximum torque of the motor MG2 at the revolution speed Ne has accordingly been set to the drive limit Tlim. Setting the torque command Tm2* of the motor MG2 in this manner enables the torque demand Tr*, which

20   is to be output to the ring gear shaft 32a or the drive shaft, to be set as a restricted torque in the range of the output limit of the battery 50 and by the rated maximum torque of the motor MG2. Equation (4) is easily derived from the alignment chart of Fig. 5 discussed above.

25

$$Tmax = (Wout-Tm1*\ddot{y}Nm1)/Nm2 \qquad (3)$$

$$Tm2tmp = (Tr^* + Tm1^*/\ddot{y})/Gr \qquad (4)$$

After setting the target revolution speed Ne* and the target torque Te* of the engine 22 and the torque commands Tm1* and Tm2* of the motors MG1 and MG2, the CPU 72 sends the target revolution speed Ne* and the target torque Te* of the engine 22 to the engine ECU 24 and the torque commands Tm1* and Tm2* of the motors MG1 and MG2 to the motor ECU 40 (step S210) and exits from this drive control routine. The engine ECU 24 receives the target revolution speed Ne* and the target torque Te* and carries out fuel injection control and ignition control of the engine 22 to drive the engine 22 at a drive point defined by the target revolution speed Ne* and the target torque Te*. The motor ECU 40 receives the torque commands Tm1* and Tm2* and carries out switching control of switching elements in the inverters 41 and 42 to drive the motor MG1 with the torque command Tm1* and to drive the motor MG2 with the torque command Tm2*.

In the case with a drive restriction of the motor MG2, on the other hand, the routine gives an affirmative answer at step S130 and determines whether the input accelerator opening Acc is not greater than a preset reference opening Aref (step S140). The preset reference opening Aref is used to determine whether the driver requires a heavy load to the vehicle and is set equal to, for example, 30% or 40%. When the input accelerator opening Acc is not greater than the

preset reference opening Aref, the CPU 72 specifies a light

load state and executes a light load correction routine shown

in the flowchart of Fig. 6 to correct a target drive point

of the engine 22 defined by the target revolution speed Ne*

5   and the target torque Te* (step S150).   When the input

accelerator opening Acc is greater than the preset reference

opening Aref, on the contrary, the CPU 72 specifies a heavy

load state and executes a heavy load correction routine shown

in the flowchart of Fig. 7 to correct the target drive point

10   of the engine 22 defined by the target revolution speed Ne*

and the target torque Te* (step S160).

        The light load correction routine first reads observed

charge-discharge electric powers Wb and a charge-discharge

electric power demand Wb* of the battery 50 (step S300) and

15   calculates an average charge-discharge electric power Wbave

of the observed charge-discharge electric powers Wb read in

a preset time period (for example, in 1 second) (step S310).

Here the observed charge-discharge electric power Wb of the

battery 50 is obtained as the product of a voltage Vb between

20   terminals of the battery 50 measured by a voltage sensor 51a

and a charge-discharge current Ib measured by a current sensor

51b and is input from the battery ECU 52 via communication.

The charge-discharge electric power demand Wb* is obtained

by conversion of the charge-discharge power demand Pb*.   The

25   routine   then   calculates   a   difference   (electric   power

difference) W between the charge-discharge electric power

demand Wb* and the calculated average charge-discharge electric power Wbave (step S320) and corrects the target revolution speed Ne* of the engine 22 to cancel the electric power difference W (step S330). The procedure of this embodiment adds the product of the electric power difference W and a proportional gain kb to a previous value of the target revolution speed Ne* set in the previous cycle, so as to correct the target revolution speed Ne*. The light load correction routine varies the target revolution speed Ne* at the target drive point of the engine 22 to cancel the difference between the charge-discharge electric power demand Wb* and the calculated average charge-discharge electric power Wave, that is, to make the observed charge-discharge electric power Wb of the battery 50 equal to the charge-discharge electric power demand Wb*, while keeping the target torque Te* unchanged. Fig. 8 shows a driving line of the engine 22 and a process of correcting the target drive point of the engine 22. Fig. 9 shows the relation between the power of the engine 22 and the power of the motor MG2 in the ordinary state and under the drive restriction of the motor MG2. As shown in Fig. 8, the target drive point of the engine 22 is changed from a drive point DP1, which is the intersection of a driving line of the engine 22 and a curve of constant power demand Pe*, to a drive point DP2 of a lower target revolution speed Ne*. The power output from the engine 22 is thus equal to the product of the corrected target revolution

speed Ne* and the target torque Te* of the drive point DP2. The charge-discharge electric power Wb of the battery 50 under the drive restriction of the motor MG2 is thus equal to that in the ordinary state, as shown in Fig. 9.

5   The heavy load correction routine sets the target revolution speed Ne* and the target torque Te* of the engine 22 as the intersection of a heavy load driving line and the curve of constant power demand Pe* (step S400 in Fig. 7). Fig. 10 shows a process of correcting the target drive point

10   according to a heavy load driving line. As illustrated, the target drive point of the engine 22 is changed from a drive point DP1, which is the intersection of an ordinary state driving line and a curve of constant power demand Pe*, to a drive point DP3, which is the intersection of a heavy load

15   driving line and the curve of constant power demand Pe*. Changing the target drive point to increase the target torque Te* in this manner enhances the torque (Te*/(1+)) transmitted to the ring gear shaft 32a among the torque to be output from the engine 22 (the target torque Te*). A torque that is still

20   smaller than but is closer to the torque demand Tr* can thus be output to the ring gear shaft 32a or the drive shaft under the drive restriction of the motor MG2.

On completion of the correction of the target drive point of the engine 22, the routine executes the processing

25   of steps S170 to S200 to set the torque commands Tm1* and Tm2* of the motors MG1 and MG2. In this cycle of the routine, there

is a drive restriction of the motor MG2. The drive limit Tlim

has thus been set as 60% or 50% of the rated maximum torque

of the motor MG2 at the revolution speed Ne. The processing

of step S200 sets the smallest among the torque limit Tmax,

5   the tentative motor torque Tm2tmp, and the drive limit Tlim

to the torque command Tm2* of the motor MG2. The torque

command Tm2* of the motor MG2 is accordingly set by restricting

the torque demand Tr* to be output to the ring gear shaft 32a

or the drive shaft in the range of the output limit of the

10   battery 50 and in the drive restriction of the motor MG2.

The target revolution speed Ne* and the target torque

Te* of the engine 22 corrected as discussed above and the

settings of the torque commands Tm1* and Tm2* of the motors

MG1 and MG2 are respectively sent to the engine ECU 24 and

15   the motor ECU 40 (step S210). The engine ECU 24 and the motor

ECU 40 control the engine 22 and the motors MG1 and MG2 to

ensure output of the torque command Tm1* from the motor MG1

and output of the torque command Tm2* from the motor MG2 and

thereby to drive the engine 22 at the target drive point

20   defined by the target revolution speed Ne* and the target

torque Te*.

As described above, the hybrid vehicle 20 of the

embodiment corrects the target drive point of the engine 22

to make the observed charge-discharge electric power Wb of

25   the battery 50 equal to the charge-discharge electric power

demand Wb*, while keeping the torque of the engine 22

unchanged, during a drive in the light load state and under the drive restriction of the motor MG2. This arrangement effectively prevents the battery 50 from being excessively charged and deterioration of the emission. During a drive in

5 the heavy load state and under the drive restriction of the motor MG2, the hybrid vehicle 20 corrects the target drive point of the engine 22 to increase the target torque Te*. A torque that is still smaller than but is rather closer to the torque demand Tr* can thus be output to the ring gear shaft

10 32a or the drive shaft. This arrangement ensures output of a desired torque in response to the driver's manipulation even under the drive restriction of the motor MG2. In the absence of a drive restriction of the motor MG2, the torque demand Tr* is output to the ring gear shaft 32a or the drive shaft

15 in the range of the output limit Wout of the battery 50 and in the range of the rated maximum torque.

The hybrid vehicle 20 of the embodiment effects the drive restriction of the motor MG2 when the temperature Tm of the motor MG2 or the temperature Tinv of the inverter 42

20 is not lower than the upper limit motor temperature or the upper limit inverter temperature. The drive restriction of the motor MG2 may be effected according to any suitable factor other than the temperature Tm of the motor MG2 or the temperature Tinv of the inverter 42.

25 In the hybrid vehicle 20 of the embodiment, the drive limit Tlim of the motor MG2 is set as 60% or 50% of the rated

maximum torque of the motor MG2 at the revolution speed Nm2. The drive limit Tlim is not restricted to the value 60% or 50% but may be greater or smaller. The drive limit Tlim may be a variable that has a stricter restriction with an increase

5   in temperature Tm of the motor MG2 or an increase in temperature Tinv of the inverter 42.

In the hybrid vehicle 20 of the embodiment, under the drive restriction of the motor MG2 and in the heavy load state, the target drive point of the engine 22 is changed to the drive

10 point DP3, which is the intersection of the heavy load driving line and the curve of constant power demand Pe*. Another technique may alternatively be applied to set the target drive point.

In the hybrid vehicle 20 of the embodiment, the power of the

15 motor MG2 is subjected to gear change by the reduction gear 35 and is output to the ring gear shaft 32a. In one possible modification shown as a hybrid vehicle 120 of Fig. 11, the power of the motor MG2 may be output to another axle (that is, an axle linked with wheels 64a and 64b), which is different

20 from an axle connected with the ring gear shaft 32a (that is, an axle linked with the wheels 63a and 63b).

In the hybrid vehicle 20 of the embodiment, the power of the engine 22 is output via the power distribution integration mechanism 30 to the ring gear shaft 32a

25 functioning as the drive shaft linked with the drive wheels 63a and 63b. In another possible modification of Fig. 12, a

hybrid vehicle 220 may have a pair-rotor motor 230, which has an inner rotor 232 connected with the crankshaft 26 of the engine 22 and an outer rotor 234 connected with the drive shaft for outputting the power to the drive wheels 63a, 63b and

5 transmits part of the power output from the engine 22 to the drive shaft while converting the residual part of the power into electric power.

The embodiment discussed above is to be considered in all aspects as illustrative and not restrictive. There may be

10 many modifications, changes, and alterations without departing from the scope or spirit of the main characteristics of the present invention. The scope and spirit of the present invention are indicated by the appended claims, rather than by the foregoing description.

15

Industrial Applicability

The technique of the invention is applicable to the automobile industry and the drive system manufacturing industry.